Exploring the world of data acquisition.

It's an analog world out there, and it's often hard to extract meaningful data from it all. In my work, I often use Data Acquisition equipment to gather the information I need and bring meaning to the operation of the systems I'm working on. In keeping with this column's unofficial theme of introducing new technologies and ideas to the above-average ham (that's you, gentle reader), I'd like to share a quick peek at the world of Data Acquisition and offer some thoughts on what you can do with it.

Data Acquisition is simply the gathering of data. You can do this by hand - read a voltage every minute and write it down - but I'm thinking more of the automated way, with a computer. Let's start with the premise that everything can be converted into a voltage. That means temperature, pressure, resistance, frequency, power, movement, etc. can all be sensed and represented by a voltage that changes in some proportion to the original 'signal'. Now that the world has been reduced to a set of voltages, let's apply some electrical engineering in an attempt to make sense of it all.

As I stated before, it's an analog world, but the computers we all use work in the digital world of 1's and 0's. What we need is a way to convert an analog voltage into a digital number that represents that voltage. For this, we use an Analog-to-Digital Converter, or A/D for short. (You can also get a D/A, or Digital-to-Analog converter, to go the other way). To help explain how an A/D works, think of a comparator circuit, which is a special type of operational amplifier (op-amp for short). A comparator's output has only two states, high (1) or low (0), which changes state at a pre-set "threshold" voltage. If we gather enough comparators, and set their thresholds carefully, we can sample any voltage and create a digital number which represents it. However, doing this with individual op-amps is tedious, costly and prone to error.

In the real world, we'd simply buy the A/D chip that meets our needs. 12 bits is the usual standard, offering a 1 part in 4096 resolution, while 16 bits or more is often used for precision work, and 8 bits for less demanding applications. Look in the Digi-Key catalog, or visit the Burr-Brown web site, to see the wide variety of A/D offerings.

Being a quintessential Ham, that is, much too cheap to buy my own hardware, to write this article I borrowed an 8-bit A/D board from my colleague Jim(1). This board is configured as a 4-input data acquisition system, and comes complete with software, making the nuts and bolts part of the process trivial. He bought it from Dataq for $15,

and spent the extra $15 for the password to enable all four channels. While it's 8-bit resolution (1 part in 256) won't launch the space shuttle, it certainly is precise enough to monitor a remote repeater site. See Figure 1.

Consider this: Data Acquisition (DAQ) is much like using an oscilloscope, only slower. Instead of monitoring signals that vary in microseconds, we are able to look at and record signals that vary in timeframes of seconds to days. You wouldn't use DAQ to measure an audio signal's frequency (although you could), but you would use it to monitor temperature, sunlight, battery voltage - any signal that varies relatively slowly. (For the purists out there: yes, there are DAQ systems that can measure into the MHz region, but have you priced them?)

Some points to consider when using A/D converters:

Sampling speed and sample rate: Although Nyquist implies that you can sample a 100 Hz signal at 200 samples per Second (s/S), that's a theoretical value. In the real world, the results will be poor. The A/D's sampling speed is the limiting factor on how fast the signal of interest can vary. If the bandwidth of the signal being sampled is not limited, you can get some weird and misleading data, as seen in Figure 2. Remember that in a multi-channel system, the sample rate is divided across all the active channels, so at a 240 s/S rate each of four channels is sampled at a speed of only 60 s/S. If this was used to look at 60 Hz power line frequency, the results would be meaningless, since the sample speed is too slow, even though the sample rate seems adequate.

Resolution: As I mentioned before, an 8-bit A/D has a resolution of 1 part in 256. In practical terms, this means I can only measure to the nearest 78 millivolts when my 8-bit Data Acquisition board has a full-scale range of -10 V to +10 V. If you spend the extra money for a 12-bit board, you can measure to the nearest 2 millivolts - but do you really need it?

The important point is that all of the A/D's bit resolution is spread out across it's full input range. For the Dataq board, this is -10 V to +10 V. If we have a signal that changes by only a few millivolts, we can still use the 8-bit system if we amplify the signal by a known amount. Using an amplifier with a fixed gain of 100 or 1000, we can make the signal large enough to sample with the accuracy we want, at a much lower cost. Instrumentation amplifiers are available commercially, or you can build your own using op-amps. See Figure 3.

If the signal of interest is greater than the input range of the DAQ, we risk either missing some data, or worse, damaging the DAQ itself. Again, with an input range of -10 V to +10 V, you can't measure most signals in a car, with it's 12 volt electrical system. The solution here is a simple voltage divider. I generally use a 1:2 divider made of two precision 500 k resistors, tapping off the center for the DAQ. The ratio of the resistors

can be varied as necessary, but kkeep the values high to avoid loading down the circuit under test.

In both cases (amplification and voltage division) you want to keep the input signal to the DAQ as close to full range as possible, to avoid losing resolution, without exceeding the maximum.

Sensors

You can make or buy sensors to convert just about anything into a voltage so you can monitor it. For temperature, we use thermistors or, for more accuracy, thermocouples. Without amplification, an 8-bit board generally doesn't have the resolution for either. Pressure sensors are available in a wide variety of pressure ranges and materials for resistance to nearly any chemical. A nice pressure sensor kit is sold by Fluke for use with a digital multimeter. Current measurements are done with a current shunt, while light can be measured with a solar cell or photoresistor. You can buy a Frequency to voltage converter IC for a dollar or two. There are sensors to detect chemical properties (such as pH), acceleration, and lots more. Resistance is measured using a constant current source to convert the variable resistance to a varying voltage. With a potentiometer, you can sense rotational position or, if you add some string, linear position. Small movements or stresses can be measured with strain gauges. You could write a book on sensors alone.

Inputs

There are three basic input methods: single-ended, differential, and isolated. If we want to monitor a simple voltage, such as the output of a solar cell, we can use a "single ended" input. This means that only one signal wire goes to the DAQ input and a common ground point for all inputs is used. Single ended signals are not very resistant to electrical noise, and you need to be careful that multiple input signals don't influence each other.

To increase noise resistance, we use differential inputs. Here, we use two inputs per signal, one for each sensor wire, and then compare them afterwards to determine the input voltage. Any electrical noise induced into the system will affect both wires nearly equally. This leaves the difference between the two wires unchanged, thus the noise doesn't affect the measurement.

If the system you're testing shares a ground with your DAQ's power supply, you can get a ground loop, which can greatly affect your measurements. Also, if the system under test carries hazardous voltages - hazardous to your equipment, to you, or both - you want to use an isolated input. The use of an optoisolator would handle this nicely, and many of the more expensive DAQs offer isolated inputs as standard equipment.

Software is the key to successful data acquisition. DAQ software can be as simple as a dumb terminal program, which gathers the raw data for later analysis, perhaps using a spreadsheet program like Microsoft Excel, or it can be as sophisticated as national Instrument's LabView, which allows you to drag and drop virtual instruments, calculation and filtering modules, and more, into the 'path' of the data channel, greatly simplifying data interpretation. One key feature to have is a real-time data display - you want to see what you're recording. The WinDAQ Lite software that comes with the Dataq board is adequate for most tasks, assuming you're running MS Windows. Strawberry Tree makes software for the DOS environment, allowing that old 8086 to serve as a dedicated DAQ recording system.

I'll close this month with some ideas for using a simple data acquisition system.

After adding a room to my hose, I wanted to monitor the effectiveness of the central air conditioning system, since calculations showed the system capacity was not quite enough for the load. I set up four channels - outside, inside and cooled air temperatures, and sunlight (using a solar cell) and sampled once every 30 seconds for a month. With this data, I learned that the system was marginal, but not enough to justify replacing it.

A very remote packet node was monitored over the winter, remotely (via Packet), to verify that the heating and battery systems were really up to the task. (They were). A repeater can be monitored for environmental conditions - is a cooling fan needed? - and how often it's being used. I once monitored the weather for months, just for the learning experience. Just how cold does it get out in my garden shed, where all my packet gear is located?

Data Acquisition is nothing more than gathering information. Automated systems can ease the task, and often do a better job. Nearly any signal can be converted into a voltage for easy recording, and sensors for just about anything exist. You can get into this fascinating field for less than a nice lunch, and the possibilities are endless. Once you have a DAQ system, ideas for it's use will flow freely. Despite the fact that I took the cheap way out, I encourage you to get a DAQ system and see for yourself what I mean.

In closing, I want to once again thank everyone who writes with questions, comments, and ideas for future columns. Most of us regular writers don't do this for the money, our real pay is mail from you, the readers. I enjoy hearing from each of you. Until next time, 73 -N2IRZ

Footnotes:

(1)   Jim dared me to explain in print why I didn't buy my own, and said I could
        borrow the board again sometime if I mentioned his name. Write to me and I'll
        ask Jim if you can borrow it, too.

Resources:

Dataq (http://www.dataq.com) offers a complete line of Data Acquisition systems,
ranging from the $15 DI-194 system I borrowed, to ones costing thousands of dollars.
Their WinDAQ software is particularly easy to configure and use.

Burr-Brown (http://www.burrbrown.com) makes A/D and D/A converters, as well as
instrumentation amplifiers.

National Instruments (http://www.ni.com) is another large company selling DAQ
systems. Their LabView software is the industry standard.

Omega (http://www.omega.com) offers an extensive line of sensors, instrumentation
amplifiers, and DAQs. Their catalog is a college education in Data Acquisition, and I
highly recommend asking for one.

There are literally hundreds more companies offering DAQ related products. Look in any
engineering magazine or search the web, the resources to learn about this fascinating area
are boundless.

Captions

Figure 1: The Dataq DI-194 four channel Data Acquisition board. Dataq sells these for
$15 on their web site, complete with software, and they're a great way to get started in
DAQ. Power is derived directly from the PC's serial port, and a convenient connector
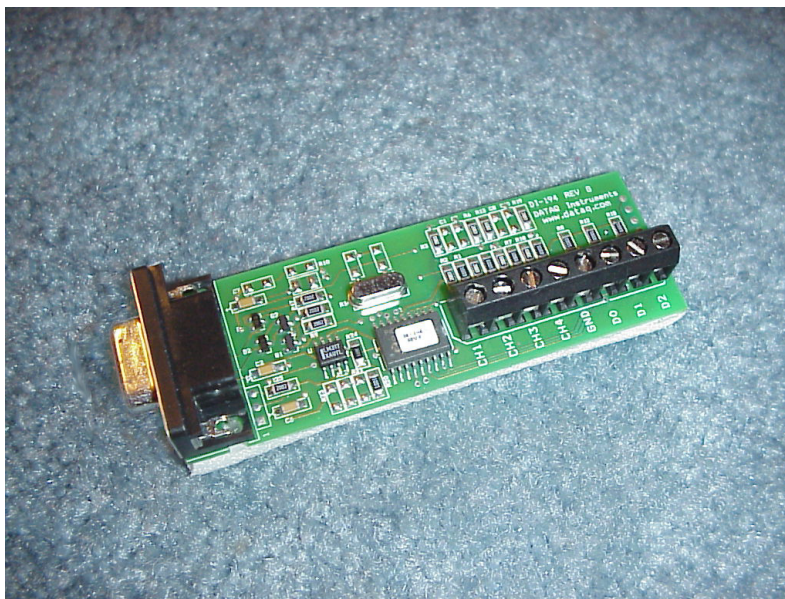block simplifies connections.

Figure 2: The dangers of not considering sampling rate and signal frequency. Here, the dots show the signal being sampled at exactly twice the frequency, but the recorded data would show no signal at all. If the sample point is shifted (squares), the frequency is correct, but the amplitude is wrong. The triangles show a higher sample rate, which results in a distorted waveform.
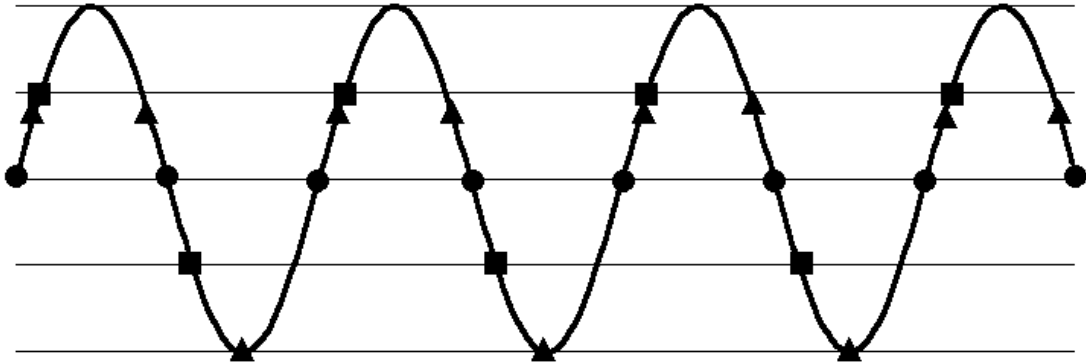

Figure 3: A simple instrumentation amplifier with a gain of 10. This basic circuit can be built with most any op-amp, and perform well, but don't expect laboratory quality results. This should be powered from a split power supply (+10 and -10 V) to allow full voltage swing. Any DC bias can be removed using a small capacitor at the input, although some measurements might require DC coupling. High quality amplifiers are commercially available.